MEASUREMENT AND COMPUTATION OF POWER LOSSES IN SOFT MAGNETIC COMPOSITE MATERIALS

Vladimir Dmitrievskii, Vladimir Prakht, Vladimir Klimarev
dept. Electrical Engineering and Electric Technology Systems
Ural Federal University, Russia
E-mail: emf2010@mail.ru

***Abstract*— In this paper a new macroscopic FEM-oriented methods of mathematical modeling and a classification of electrical losses in SMC materials is discussed, the experimental data are provided and its processing is considered.**

***Keywords* - soft magnetic composites, eddy current losses, hysteresis losses, numerical analysis**

I. INTRODUCTION

Soft magnetic composite (SMC) materials have gained wide-spread acceptance in electromechanics and electrical engineering. SMC materials consist of iron microparticles referred to as grains which are covered with a thin layer of the binding dielectric. In developing high speed electrical machines, SMC materials offer their major advantage over the electrical steel in their having greater electrical resistance attributed to their granular structure, which significantly reduces eddy current losses.

Electrical machine parts made of SMC materials can be of arbitrary shape and produce magnetic fluxes of arbitrary configuration, which makes it possible to develop, e.g., claw pole stator electrical machines, reduce the magnetic lines' length, remove the windings' front parts producing no useful magnetic field, and, eventually, increase specific power and efficiency.

Measuring magnetic properties of soft magnetic materials of the ring shape and rectangular cross-section (hollow cylinders) is specified by the standard [1]. In particular, the standard [1] specifies the procedure for determining the magnetic induction amplitude dependence of power loss specific density. The procedure presented in the standard [1] allows determining specific losses in the specimen only of the ring shape with a small rectangular cross-section, and the ratio between the outer diameter D and the inner one d not exceeding 1.4 (preferably not more than 1.25), using the data measured. Without using mathematical modeling of losses in SMC materials, the data obtained cannot be applied to ring-type specimens of a big cross-section as well as specimens of another shape, where the magnetic field configuration differs from that in the ring. That is why, the results of measuring losses in SMC materials cannot be applied directly in designing products made of SMC materials, without using mathematical modeling. Losses in SMC materials are of a different nature and depend differently upon the electromagnetic conditions under which the specimen is placed. Because of this, mathematical modeling of losses in SMC materials implies classifying losses, determining the procedure of assigning losses to this or that loss type and developing mathematical models of these types of losses.

In [2], losses in SMC materials are classified as hysteresis losses, classical losses and excess losses. Hysteresis losses are attributed to the energy lost on SMC reverse domains' magnetization; classical losses as well as the so-called eddy current losses are due to the flow of eddy currents induced by the changing magnetic field inside the grain; excess losses are caused by the non-uniformity of the grain reverse magnetization process and the domain walls movement. In [2], it is shown that within one cycle hysteresis losses are virtually independent of the reverse magnetization frequency; the energy within one cycle of excess losses similar to the eddy current losses is proportional to the frequency, which makes SMC materials differ from laminated steel where the energy of excess losses is proportional to the frequency square root. The paper [2] studies the specimens of such a small cross-section that the macroscopic eddy currents flowing between the grains due to the imperfect isolation can be neglected. As a result, the paper [2] makes a conclusion that the eddy currents in SMC materials are restricted within separate particles, the statement is disputed in [3], [4].

A restriction on the specimen's cross-section which allows the eddy currents flowing between the grains to be neglected was removed in [3], where eddy current losses are sundivided into inter-particle and intra-particle eddy current losses. Intra-particle eddy current losses are due to the eddy currents flowing inside the grain. Inter-particle eddy current losses are associated with those attributed to eddy currents flowing between the grains due to the damage of the insulating film covering the grains; they are calculated based on the material's specific resistance. The paper [3] contains the expression to be used for calculating intra-particle eddy current losses in the specimens of the ring shape with a rectangular cross-section.

In [4], on the basis of a microscopic model structure, having a regular 3-dimensional distribution of cubic grains, where the grain-to-grain contact resistance has randomly distributed values, a proposal is made that the specific resistance can slightly grow when the area of the ring's cross-section increases. The specific resistance growing with the increase of the grain's cross-section area is explained by lowering the possibility for the electric current path breaking caused by an accidental contact allocation between the grains. The results presented in [4] are tested on the rings of 6.25mm^2 and 25 mm^2 cross-section.

In [2]-[4], techniques of mathematical modeling (based on microscopic properties) electrical losses in SMC materials, are described, that are based on physical principles and the granular structure of SMC materials. These techniques of loss mathematical modeling require the information on the grain size, insulation properties and its imperfections, understanding the processes of domains' reverse magnetization, including the peculiarities of domain walls movement, as well as great computational resources to model the electromagnetic processes in the specimen consisting of a great number of grains. However, as the grains' sizes are substantially less than those of the products made on the basis of SMC materials, in designing electrical machines, SMC materials can be considered as an ideal homogeneous medium. In doing so, the electromagnetic calculation is performed using Maxwell's equations for continuous media, which alongside with constitutive equations make a system of equations for macroscopic fields. That is why the electromagnetic design of electrical machines requires material equations connecting macroscopic electromagnetic values, and ways of calculating specific losses in SMC materials.

This paper proposes methods of mathematical modeling and a classification of electrical losses in SMC materials, based on macroscopic properties: 1. Hysteresis losses. The energy density in hysteresis losses within one cycle of reverse magnetization does not depend either on frequency or the shape of the sample made of SMC material. These losses actually correspond to hysteresis losses in [2]; 2. Intra-particle eddy current losses. As distinguished from [3], in order to consider the increase of specific conductivity caused by the increase of the cross-section, model representations of not only volume resistivity (unit measurement is Ohm*m) but also surface resistivity (measured in Ohms) being available are introduced; 3. Excess losses are all the rest ones. The energy density of these losses within one cycle is proportional to the frequency as well as to the square of magnetic induction and does not depend upon the specimen's shape. As distinct from [2], intra-particle eddy current losses are added to the excess losses as well.

It should be noted that as the specific energy within one cycle of reverse magnetization of excess losses is proportional to the frequency and the square of magnetic induction, in modeling electromagnetic processes on the basis of Cauchy problem, the excess losses power can be considered to be proportional to the square of the time derivative of the magnetic induction. This proposal due to its simplicity can be applied to calculate specimens made of laminated steel, as for the specimens made of SMC materials, it assumes still greater support.

II. Experimental Unit and Power Loss Modelling Methods

The experimental unit is constructed in accordance with its representation in Fig. 11. The ring made of the MSC material is wound with the primary and secondary windings of N1 and N2 turns. The primary winding is connected to the sinusoidal voltage supply through the shunt (R) that allows measuring the current (I) in the primary winding. A digital oscillograph measures the shunt voltage (V_1) and the voltage in the secondary winding (V_2).

At present, there are measurements made for induction of sinusoidal waveforms the maximum value of which is 0.3 to 1.6 T in the frequency range of 5Hz – 3 kHz, using rings made of various Somaloy materials of Höganäs' production, having the following dimensions: D=55mm, d=45mm, h=5mm (the specimens of S_1 cross-section); D=64mm, d=35mm, h=15mm (the specimens of S_2 cross-section), where h is the ring's height. For the ring of S_2 cross-section, D/d=64/35=1.8, which exceeds the maximum ratio of D/d =1.25, allowed by the standard [1]. As the magnetic field strength is inversely proportional to the distance of the symmetry axis, increasing the ratio D/d results in increasing the non-uniformity of the magnetic field. That is why, a special algorithm for processing experimental data obtained using the rings with D/d>1.25 is described in this paper, that allows the non-uniformity of the magnetic field to be taken into account in interpreting the experimental data taken with the rings of D/d>1.25.

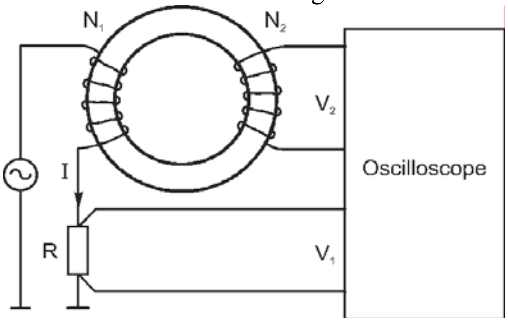

Fig. 1. The unit to measure power losses in SMC materials

On the basis of experimental data received, categorization of losses has been performed in accordance with the classification proposed and the methods of macroscopic mathematical loss modeling in SMC materials.

In the immediate future, experimental research in the Somaloy materials of other cross-sections and shapes is to be conducted aimed at testing if the methods proposed are appropriate to be applied to the SMC specimens of unspecified shapes. This testing will be correlating the experimental results with those of modeling the electromagnetic processes in the specimen.

An extended version of the paper will include the description of the methods to be used for experimental data processing, a detailed description of the proposed SMC losses mathematical modeling techniques that are based on macroscopic SMC materials' properties and discussion of the results obtained. Recommendations will be given on applying the proposed methods in FEM designing electrical machines.

References

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